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Reference-Building Equivalent Energy Performance Targets for Canada's Housing Energy Code

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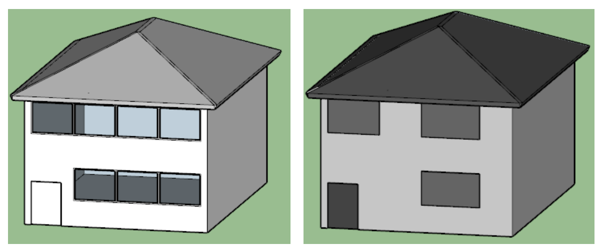
Abstract

Canada's National Building Code (NBC) requires builders to use the reference-building approach for its performance compliance path. It is well understood that the reference-building approach does not recognize the benefit of architectural form in the design of energy efficient buildings. In 2022, the Canadian Board for Harmonized Construction Codes established a task group for developing an alternate absolute performance compliance path in the NBC. This group was faced with the challenge of setting absolute energy performance targets that are consistent with the code's current energy efficiency requirements. This paper developed a methodology for determining energy performance targets that align with the reference-building targets of the NBC's performance path. It then evaluated potential design outcomes associated with the proposed absolute energy performance targets, expecting that houses with a wall-to-floor area ratio of less than 1.0 and window-to-floor area ratio of less than 0.2 will show a better energy performance under the proposed absolute performance compliance path than the NBC's existing reference-building performance compliance path. The proposed absolute energy performance targets for tiers 3 and 4 are in good agreement with the British Columbia (BC) Energy Step Code, however the proposed targets for tier 5 are more stringent than the BC Energy Step Code.

Introduction

Several countries have adopted an absolute performance compliance path in their building energy codes. Examples include Germany's EnEV (Galvin, 2010; Schettler-Köhler & Ahlke, 2018a), Sweden's Building Regulations (Allard et al., 2017), and Building Energy Efficiency Standards of California (2019). These code authorities prefer absolute energy performance targets in lieu of the reference-building approach due to the limitations of the latter approach in designing energy-efficient buildings (Schettler-Köhler & Ahlke, 2018b; Liu et al., 2019). For instance, the reference-building approach is insensitive to buildings' forms as a proposed building and its associated reference building have identical geometry (Figure 1) (Gilani et al., 2022; Foroushani et al., 2022). Casals' (2006) study of European building energy codes argued that the reference-building approach leads to housing forms that are less compact and consequently less energy efficient.



Proposed Building ***Reference Building***

Figure 1 Identical geometry between a proposed building and its associated reference building.

In Canada, builders choosing the performance path for compliance with the National Building Code (NBC) must use the reference-building approach (CCBFC/NRC, 2020). However, some jurisdictions such as the British Columbia (BC) Energy Step Code (BC Housing, 2017) and Toronto Green Standard (City of Toronto, 2018) have adopted the absolute performance compliance path as an alternative compliance path. In 2022, the Canadian Board for Harmonized Construction Codes (CBHCC) has established a task group to develop an absolute performance compliance path as an alternative performance compliance path in the NBC.

As the task group did not know how to determine absolute energy performance targets in a way that aligns with the current reference-building targets of the NBC, this research developed a methodology for this purpose. This methodology included development of simple linear regression models for determining absolute energy performance targets based on the most influential factors. Expected design outcomes of the proposed absolute energy performance targets were also investigated in this research.

Methodology

This section explains what performance metrics this research proposes for the presented absolute performance compliance path, and the methodology developed for determining absolute energy targets for each performance metric.

Performance Metrics

The NBC requires three energy performance metrics for the performance compliance path: (1) annual gross space heat loss (*GSHL*), (2) annual mechanical energy use (*MEU*), and (3) peak cooling load (*PCL*).

The *GSHL* (kWh) is a metric for evaluating energy performance of a house's envelope, excluding thermal loads from internal and solar heat gains. As per the NBC, the annual *GSHL* shall include all heat losses through the house envelope. This research proposes the annual *GSHL* intensity (*GSHLI*) (kWh/m^2) as an adaptation of the *GSHL* metric through normalizing *GSHL* by heated floor area of the house as per Equation (1).

$$GSHLI = \frac{HL}{A_{floor}} \tag{1}$$

where *HL* is the annual cumulative heat loss from conduction through the house envelope (both opaque and transparent), air infiltration and exfiltration, and mechanical ventilation, and A_{floor} is the heated floor area (m^2) of the house.

The annual *MEU* (kWh) shall include space heating, cooling, and ventilation, and domestic hot water energy use (*HWEU*) based on the NBC's calculation method. This research proposes the annual *MEU* (kWh) as a combination of: (1) the energy use intensity (EUI_{HVAC}) of the HVAC systems multiplied by A_{floor} of the house, and (2) hot water energy use. The annual EUI_{HVAC} and *MEU* are calculated using Equations (2), (3), and (4):

$$E_{HVAC} = E_{heating} + E_{cooling} + E_{ventilation} \tag{2}$$

$$EUI_{HVAC} = \frac{E_{HVAC}}{A_{floor}} \tag{3}$$

$$MEU = EUI_{HVAC} \times A_{floor} + HWEU \tag{4}$$

where E_{HVAC} is the energy used for space heating, cooling, and mechanical ventilation, $E_{heating}$ (kWh) is the annual energy used for space heating, $E_{cooling}$ (kWh) is the annual energy used for space cooling, $E_{ventilation}$ (kWh) is the annual energy used for mechanical ventilation, and *HWEU* (kWh) is the annual energy used for water heating.

The NBC requires calculating *PCL* (W) as a metric to reduce the overheating risk. As per the NBC, the *PCL* shall report the maximum hourly-averaged rate at which heat is removed from a house to keep the house at the cooling setpoint temperature. If a house is not equipped with a cooling system, the design cooling load under design conditions is used instead of the peak cooling load of the cooling system of the house. This research proposes the use of the *PCL* intensity (*PCLI*) (W/m^2) normalized by A_{floor} of the house.

Absolute Energy Targets

To develop reference-building equivalent energy performance targets for the *GSHLI* and *MEU* metrics, this study referenced a statistical representative sample of Canadian contemporary housing archetypes that Natural Resources Canada (NRCan) (Asaee & Ferguson, 2018) has developed based on the EnerGuide for Houses database (Natural Resources Canada, 2020) and the survey of household energy use (SHEU) (Natural Resources Canada, 2015). The open-source HOT2000 files of NRCan's 240 archetypes are available through a public GitHub repository (Natural Resources Canada, 2019b). The reference house of all the NRCan's 240 archetypes were simulated in 104 Canadian locations with various heating degree days (*HDD*s) from 2,650 to 12,360. The reference house associated with each archetype and location was generated automatically and simulated using the Housing Technology Assessment Platform (HTAP) (Natural Resources Canada, 2019a) as per the NBC's prescriptive requirements.

Among various climate and design-related parameters (Figure 2), it was found that the most influential factors on a house's *GSHLI* are *HDD* and wall-to-floor area ratio (*Wall-FR*) with a relatively high correlation of 0.63 between *GSHLI* and *HDD* and 0.68 between *GSHLI* and *Wall-FR*. It was also found that there is a strong correlation (0.72) between EUI_{HVAC} and *HDD* and there is a moderate correlation (0.51) between EUI_{HVAC} and *Wall-FR*. This research proposes using *HDD* as the the predictor variable as *HDD* is an external factor that a designer does not have control over.

The analysis on the correlation between *HWEU* and various climate and design-related parameters showed that there is a weak correlation (0.20) between *HWEU* and *HDD* and a very weak correlation between *HWEU* and *Wall-FR* (Figure 2). Hence, a constant value of 6,500 kWh/yr is suggested for *HWEU* based on the median values obtained for electrically and gas heated archetypes.

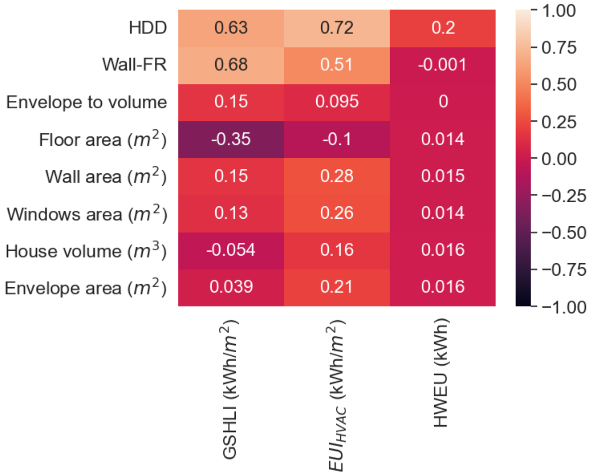


Figure 2 Correlation between metrics and climate/design-related parameters.

Once the most influential factors on *GSHLI* and EUI_{HVAC} were identified, a simple linear regression model was fit for each performance metric to develop performance targets for typical houses. Simple linear regression models were used in this research as these models are easier for users to calculate the energy targets based on only one predictor variable.

To fit simple linear regression models for each performance metric, the median *GSHLI* across reference houses of NRCan's 240 archetypes for each *HDD* was calculated. Then, a simple linear regression model was fit to the median values of *GSHLI* to describe the relationship between the predictor variable of *HDD* and the response variable of *GSHLI* (Figure 3). A simple linear regression model was also developed for EUI_{HVAC} using the same methodology to describe the relationship between the predictor variable of *HDD* and the response variable of EUI_{HVAC} (Figure 4).

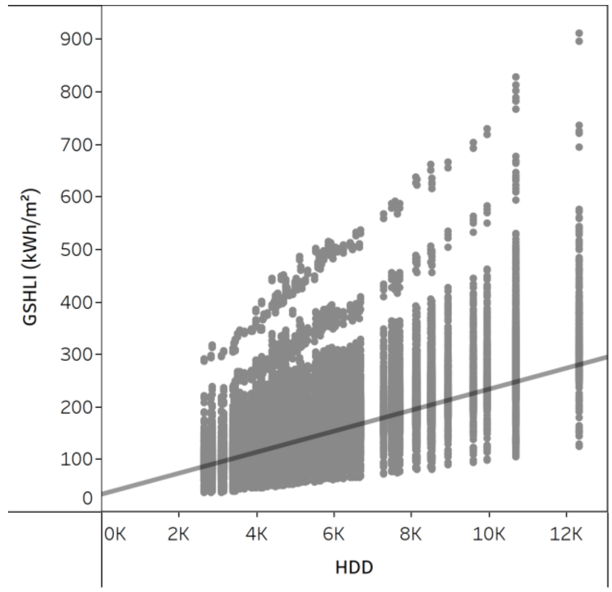


Figure 3 Relationship between GSHLI and HDD with the simple linear regression model fit to the median values of GSHLI across NRCan's 240 archetypes at each HDD.

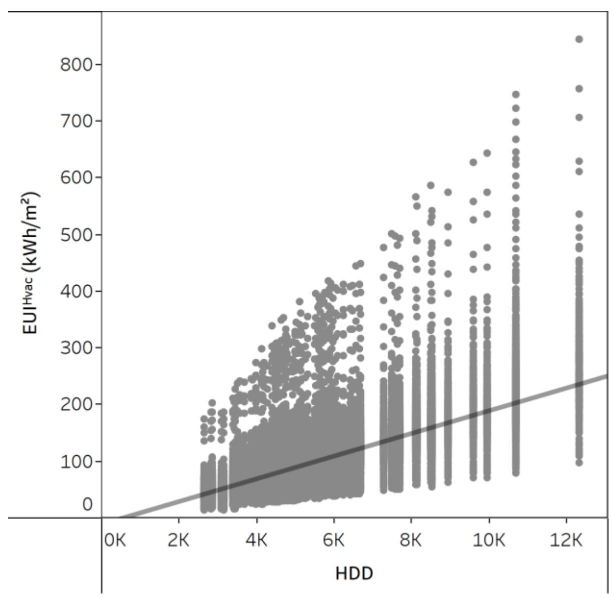


Figure 4 Relationship between EUI_{HVAC} and HDD with the simple linear regression model fit to the median values of EUI_{HVAC} across NRCan's 240 archetypes at each HDD.

Results and Discussion

This research proposes Equations (5) and (6) for calculating annual *GSHLI* (kWh/m^2) and EUI_{HVAC} (kWh/m^2)

targets for meeting tier 1 of the NBC based on a location's *HDD*. The annual *MEU* target (kWh) is then calculated using Equation (7).

$$GSHLI = 0.02 \times HDD + 32.6\ (R^2 = 0.98) \quad (5)$$

$$EUI_{HVAC} = 0.02 \times HDD - 12.3\ (R^2 = 0.98) \quad (6)$$

$$MEU = EUI_{HVAC} \times A_{floor} + 6500 \quad (7)$$

This research proposes that the *GSHLI* and *MEU* targets calculated by Equations (5) and (7) be scaled by an adjustment factor depending on the tier as per NBC's Section 9.36.7.2 (Table 1). In this way, the proposed absolute energy performance targets will be in line with the targets defined in the NBC for the performance compliance path.

A cooling load target of 15 W/m² was also considered following guidance from CBHCC task group members.

Table 1. Adjustment factors for GSHLI and MEU as per NBC's Section 9.36.7.2.

Energy performance metric	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
GSHLI	1.00	0.95	0.90	0.80	0.60
MEU	1.00	0.90	0.80	0.60	0.30

To gain insights into potential design outcomes, geometry-related characteristics of the archetypes that meet at least tier 1 of the NBC based on the proposed absolute energy performance targets were also analyzed. Using the simple linear regression models that were developed for the performance metrics of *GSHLI* and *MEU*, reference-building equivalent energy performance targets can be established for each tier of the NBC. It was then determined if reference houses of each archetype complied with the code via the proposed absolute performance compliance path based on the NBC's three requirements (i.e. *GSHLI*, *MEU*, and *PCL*).

The archetypes whose equivalent reference houses met each tier of the code via the proposed absolute performance compliance path were identified. To this end, the archetypes were first categorized into three categories (Table 2): (1) the archetypes that met the *GSHLI* and *MEU* targets for tier 1 as well as the NBC's cooling load requirement, (2) the archetypes that met the *GSHLI* and *MEU* targets for tier 1, but did not meet the NBC's cooling load requirement, and (3) the archetypes that did not meet either of the *GSHLI* or *MEU* targets for tier 1. Note that as per the NBC, Category #2 can still comply with the code via the proposed absolute performance compliance path if they are also equipped with a cooling system.

Table 2. Categorization of archetypes based on meeting GSHLI, MEU, and cooling load requirement

Category #	*GSHLI* budget for tier 1	*MEU* budget for tier 1	Cooling load
1	Pass	Pass	Pass
2	Pass	Pass	Fail
3	Pass	Fail	NA
	Fail	Pass	
	Fail	Fail	

Figure 5 presents number of archetypes in each of the three categories (see Table 2) in example cities in the six Canadian climate zones. This figure shows that about half of the archetypes do not comply with the code via the proposed absolute performance compliance path as they do not meet either the *GSHLI* or *MEU* targets, whereas about half of the archetypes comply with the code via the proposed absolute performance compliance path with the code's minimum requirement. There are even some archetypes that meet higher tiers of the code with no additional upgrades. Figure 6 presents number of archetypes that meet each tier of the code via the proposed absolute performance compliance path in example cities in each Canadian climate zone. For instance, eight archetypes can readily meet tier 5 of the code via the proposed absolute performance compliance path in Vancouver without any additional improvement in their envelope or mechanical systems.

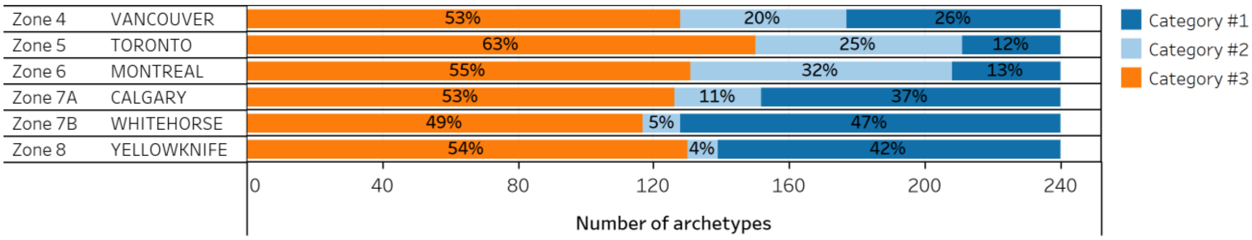


Figure 5 Number of archetypes in categories #1, 2, and 3 (see Table 2) that meet the code via the proposed absolute performance compliance path.

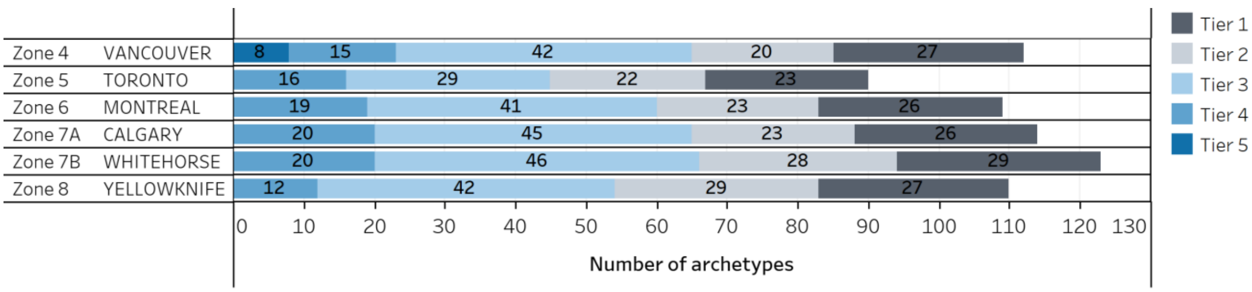


Figure 6 Number of archetypes in categories #1 and 2 (see Table 2) that meet each tier of the code via the proposed absolute performance compliance path.

Geometry-related characteristics of the archetypes that fall into Categories #1 and 2 were compared to Category #3 to identify expected design outcomes of the proposed absolute energy performance targets. Figure 7 presents *Wall-FR* bins and number of archetypes that meet the code (Category #1 and 2) and do not meet the code via the proposed absolute performance compliance path (Category #3) at each *Wall-FR* bin in example cities in each Canadian climate zone. Note that the *Wall-FR* metric is an indicator of how compact a house form is. This figure shows that none of the archetypes with *Wall-FR* of larger than 1.0 meet the code via the proposed absolute performance compliance path. This finding suggests that builders of more complex, and more articulated housing forms (with more corners) will find it harder to comply via the proposed absolute performance compliance path, although they may comply via the existing reference-building compliance path. On the other hand, the archetypes with smaller *Wall-FR* (more compact forms) will comply with the code via the absolute performance compliance path, and may readily meet the higher energy tiers of the code via the proposed absolute performance compliance path with no upgrades in their envelope or mechanical systems. For instance, the eight archetypes that meet tier 5 in Vancouver (as presented in Figure 6) have a *Wall-FR* of 0.3-0.4.

Figure 7 also shows that there are some archetypes with a *Wall-FR* of 0.6-1.0 that do not meet the code via the proposed absolute performance compliance path despite their compact forms. Further analysis of those archetypes showed that the archetypes with a *Wall-FR* of 0.6-1.0 that do not comply with the code via the proposed absolute performance compliance path (Category #3) have larger *Window-FR* compared to the archetypes with a *Wall-FR* of 0.6-1.0 that comply with the code via the proposed absolute performance compliance path (Category #1 and 2). Figure 8 presents the relationship between A_{floor}, *Wall-FR*, and *Window-FR* of the archetypes that comply and do not comply with the code via the proposed absolute performance compliance path. This figure shows that all the archetypes that meet the code via the proposed absolute performance compliance path have a *Window-FR* of less than 0.2.

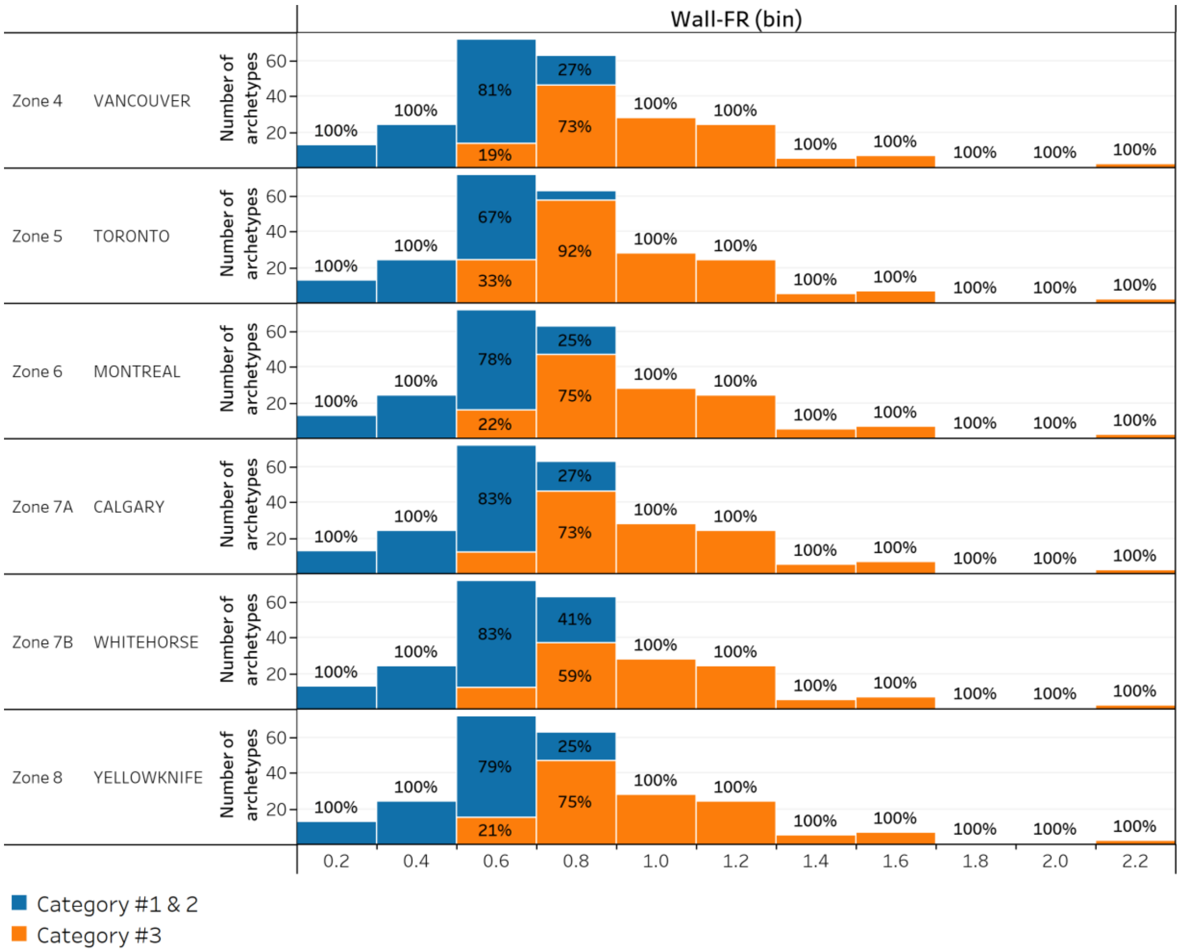


Figure 7 Number of archetypes in each of three categories (see Table 2) in an example city in each Canadian climate zone at each Wall-FR bin. Percentage values on each bar are the percentage of the archetypes that fall into each Wall-FR bin and each category.

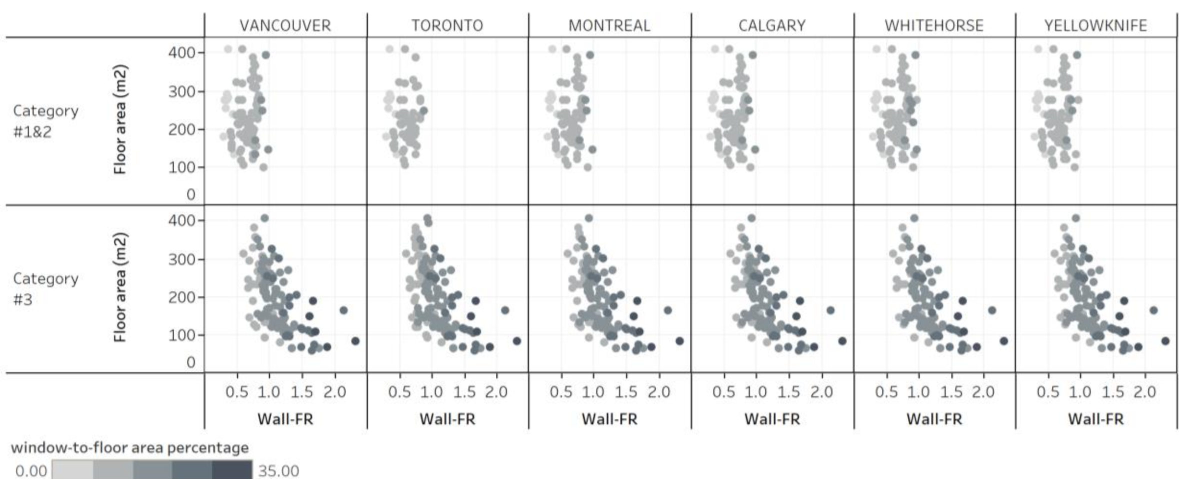


Figure 8 Relationship between floor area, Wall-FR, and window-to-floor area percentage of the archetypes that comply and do not comply with the code via the proposed absolute performance compliance path in example cities in each Canadian climate zone.

As Equations (5) and (7) provide energy targets for specific climate conditions and houses' A_{floor}, smaller houses are afforded more stringent targets while larger houses are afforded more generous targets. Hence, smaller houses face significant onus to adopt energy efficiency measures even though they use less energy than larger houses. To establish more equitable requirements for small houses, this research developed a method to estimate an A_{floor} threshold for small houses. In this method, the small house's A_{floor} threshold is identified based on the absolute (kWh) and intensity-based (kWh/m^2) values of *GSHL* and E_{HVAC}. In the proposed method, the relationship between absolute and intensity-based values of each metric is analyzed. Figure 9 shows these relationships for the *GSHL* metric of the simulation results in Ottawa. Each dot in Figure 9 represents each of the NRCan's 240 archetypes. The A_{floor} range of each archetype is shown by the color bar. The archetypes were then classified into four classes based on the median of the absolute and intensity-based values of the *GSHL* metric. Among the four classes shown in Figure 9, Class #1 represents the archetypes with energy-efficient forms and small A_{floor} as they have larger *GSHLI* compared to Class #3 and 4 while they have smaller *GSHL* compared to Class #2.

The same analysis showed similar trends for the E_{HVAC} metric (Figure 10) as *GSHLI* and EUI_{HVAC} are strongly correlated. The median of the A_{floor} of Class #1 for both *GSHLI* and EUI_{HVAC} across the 104 considered locations was calculated as 115 m^2. Hence, this research proposes a threshold of 115 m^2 as a small house's A_{floor}, meaning that if a house has an A_{floor} of smaller than or equal to 115 m^2, the house shall meet the *GSHLI* and EUI_{HVAC} of a house with an A_{floor} of 115 m^2 using Equations (5) and (6).

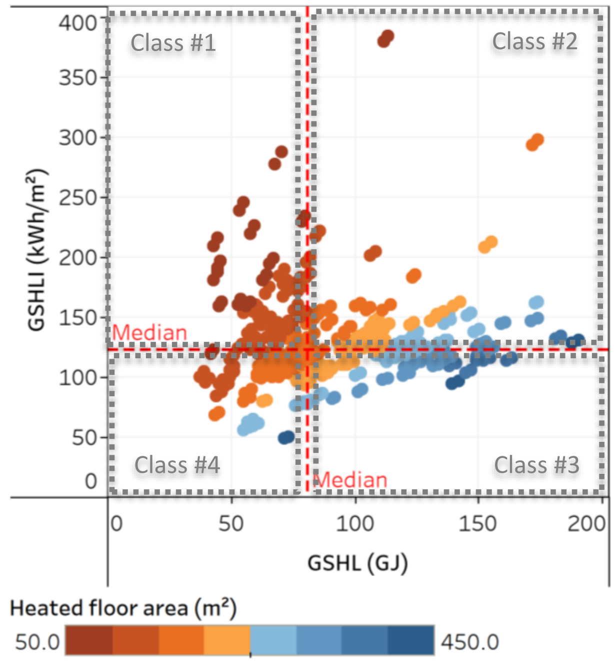


Figure 9 Simulated absolute GSHL (GJ) and GSHLI (kWh/m^2) of NRCan's 240 archetypes in Ottawa. Each dot represents each archetype. Red vertical and horizontal dashed lines represent median of GSHL (GJ) and GSHLI (kWh/m^2) across NRCan's 240 archetypes, respectively.

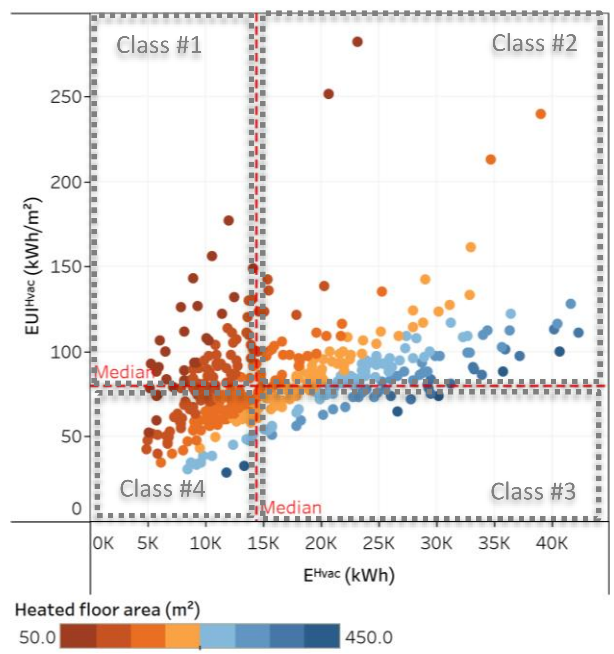


Figure 10 Simulated absolute E_{HVAC} (kWh) and EUI_{HVAC} (kWh/m^2) of NRCan's 240 archetypes in Ottawa. Each

dot represents each archetype. Red vertical and horizontal dashed lines represent median of E_{HVAC} (kWh) and EUI_{HVAC} (kWh/m^2) across NRCan's 240 archetypes, respectively.

Figure 8 also shows that the archetypes that meet the code via the proposed absolute performance compliance path have a wide range of A_{floor} of 100 to 400 m^2. There is even an archetype with an A_{floor} of about 400 m^2 that meets tier 5 of the code in Vancouver via the proposed absolute performance compliance path with no additional improvements in its envelope or mechanical systems. However, that archetype has a compact form (*Wall-FR* of 0.36), reducing its heat loss through its external envelope. If the code defines targets for only *GSHLI* and *MEU*, excluding a form factor, defining a large house's A_{floor} threshold is necessary as larger houses will have larger targets to meet the code via the proposed absolute performance compliance path based on Equations (5) and (7). This research proposes a large house's A_{floor} threshold of 350 m^2 as the 95th percentile A_{floor} of the archetypes that meet the code via the proposed absolute performance compliance path (Category #1 and 2). This threshold means that if a house has an A_{floor} of larger than or equal to 350 m^2, it shall meet the *GSHLI* and EUI_{HVAC} of a house with an A_{floor} of 350 m^2.

To evaluate the similarity between the proposed absolute performance compliance path and other intensity-based regulations, the proposed *MEU* targets were also compared to those stipulated in the BC Energy Step Code. The BC Energy Step Code defines *MEU* intensity for various ranges of *HDD* and A_{floor}, based on whether more than half of the house has cooling equipment or not. The BC Energy Step Code's energy performance requirements for houses with an A_{floor} of 200 m^2 that are equipped with cooling equipment were used. The results, as presented in Figure 11, shows a good agreement for tiers 3 and 4 (steps 3 and 4), indicating that the proposed *MEU* targets are generally consistent with the BC Energy Step Code's *MEU* requirements. However, the proposed *MEU* targets for tier 5 are considerably lower than Step 5 in the BC Energy Step Code. This suggests that the NBC's target for tier 5 (70% improvement in the proposed house's *MEU* compared to its equivalent reference house) is quite stringent compared to the BC Energy Step Code.

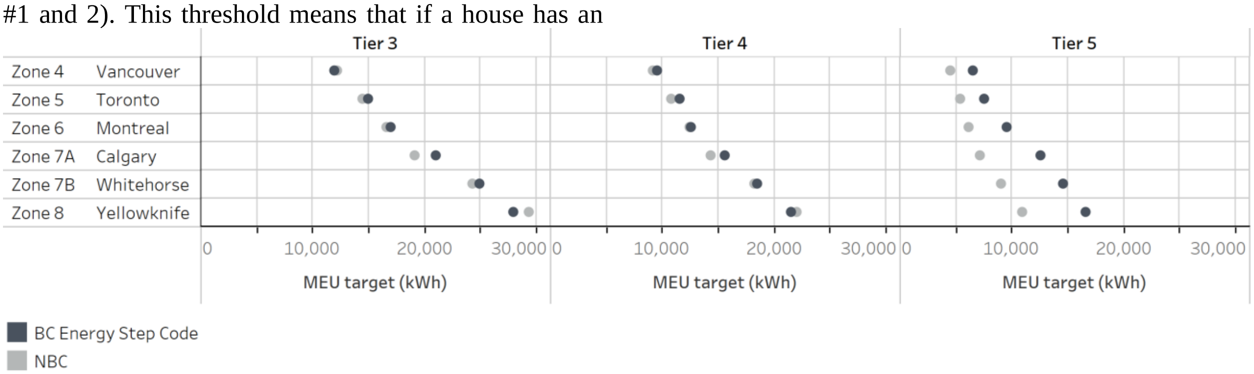


Figure 11 Comparison between BC Energy Step Code and proposed NBC's targets for MEU for a 200 m² house.

Conclusion

The present study developed a methodology for an absolute performance compliance path as an alternative to the reference-building compliance path of Canada's NBC. This methodology included development of simple linear regression models for determining annual *GSHLI* and EUI_{HVAC} targets for meeting the NBC as a function of a location's *HDD*. The annual *MEU* target (kWh) is then calculated based on EUI_{HVAC} and an annual *HWEU* of 6,500 kWh.

Based on the results, it is expected that builders of compact houses with a *Wall-FR* of less than 1.0 and smaller *Window-FR* (less than 0.2) will find the energy efficiency requirements of the proposed absolute performance compliance path to be similar to, or less stringent than the existing reference-building performance compliance path. Those houses will still demonstrate similar or lower energy use than houses with typical architectural forms that comply via the existing reference-building performance compliance path.

This study proposed heated floor area thresholds of 115 and 350 m^2 for small and large houses, respectively. These thresholds offer relaxed energy budgets to houses smaller than 115 m², thereby recognizing that smaller houses use less energy than larger houses, and that these savings should be counted towards energy efficiency targets. This research also showed that intensity-based metrics afforded larger houses unnecessarily large energy budgets, unless an upper floor area limit is also provided. For this reason, the proposed absolute performance compliance path requires that houses with heated floor areas larger than 350 m^2 meet the energy targets for a house with a heated floor area of 350 m^2, or alternatively, comply via the existing reference-building compliance path.

Comparing the proposed absolute energy performance targets with the BC Energy Step Code also showed a good agreement for tiers 3 and 4, while the proposed targets for tier 5 based on the NBC are more stringent than the BC Energy Step Code.

These proposed changes will be published for public review and comment in the spring of 2024. Upon completion of that review, CBHCC may elect to recommend their incorporation into Canada's 2025 NBC.

Acknowledgment

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